Silicon-on-Insulator Microring Resonators for Photonic Biosensing Applications

Sam Werquin[1,2], Arne Goes[2,3], Peter Dubruel[2,3], Peter Bienstman[1,2]
[1] *Photonics Research Group, INTEC, Ghent University, B-9000 Gent, Belgium*
[2] *Polymer Chemistry & Biomaterials Research Group, Ghent University, B-9000 Ghent, Belgium*
[3] *Center for Nano- and Biophotonics (NB-Photonics), Ghent University, B-9000 Ghent, Belgium*
Tel: +32 9264 3447, Fax: +32 9264 3593, e-mail: sam.werquin@intec.ugent.be

ABSTRACT
Silicon-on-insulator microring resonators have proven to be an excellent platform for label-free nanophotonic biosensors. The high index contrast of the silicon-on-insulator waveguides allows for fabrication of micrometer size sensors. Their small size combined with high sensitivity make them ideal candidates for integration in sensing arrays as a multiplexed DNA detection platform. By chemically modifying the sensor surface, the microrings can provide sequence selective DNA detection. However, the high index contrast also limits the quality of the resonances by introducing an intrinsic mode-splitting by coupling the degenerate resonator modes. This severely deteriorates the quality of the output signal. The quality of the resonances is of utmost importance to determine the performance of the microrings as a biosensor. We will suggest an integrated interferometric approach to give access to the unsplit, high-quality normal modes of the microring resonator.

Keywords: silicon-on-insulator, microring, biosensor, resonance splitting, DNA detection, lab-on-a-chip.

1. INTRODUCTION

Silicon-on-insulator (SOI) microring resonators have proven to be an excellent platform for label-free nanophotonic biosensors. The high index contrast of the SOI-platform allows for fabrication of micrometer size sensors. The small sensor size makes microring resonators excellent candidates for highly multiplexed assays [1]. It also allows for integration of a sensor on an optical fiber tip, opening the door to in-vivo applications [2]. By combining microrings in advanced sensing configurations, it is also shown that their sensitivity can be improved significantly [3]. The high index contrast of the SOI-platform causes high confinement of the optical fields in the waveguides, which makes the microrings very sensitive to changes on the waveguide surface. By coating the sensor surface with DNA sequence probes, we introduce specificity to the complementary strand. The sensors can now be used to determine whether a specific DNA sequence is present in an analyte solution. The high index contrast enables high sensitivities to changes on the microring surface, but at the same time, waveguide roughness forms an increasingly dominant limitation by scattering the guided light. This degrades the quality factor of the resonances and can ultimately lead to splitting of a resonance [4]. Because the detection limit of a microring biosensor is directly related to the quality of the ring resonance, a high Q-factor is of primordial importance in sensing applications [5]. In this paper, we demonstrate the possibility to perform complementary strand detection. We will also point out the deteriorating effect of resonance splitting and present an integrated interferometric approach to resolve the resonance splitting of a microring resonator on a single chip. This results in a significant improvement of the resonance quality.

2. COMPLEMENTARY DNA DETECTION

To realize a successful complementary DNA detection experiment, we followed the procedure described in [6]. We have packaged a fluidic flowcell on the photonic chip and performed all the chemical functionalization steps in-situ. The experiment starts by silanization of the silicon surface to link organic molecules to the sensor. This is performed by exposing the chip surface to a 2 % (v/v) succinimidyl-6-hydrazino-nicotinamidetrietoxy-silane (HYNIC-Silane) in absolute ethanol with 5 % (v/v) dimethylformamide. The reaction takes place at room temperature (25 centigrade) for 20 to 30 minutes. The activated surface possesses a stable and active hydrazine linker to bind to a DNA capture probe that has been modified at the 5' end with an aldehyde prior to reaction. Coupling takes place in 100 μM aniline in PBS pH 6 buffer with a probe concentration of 1 μM. The aldehyde of the DNA probes reacts at room temperature with the active hydrazine on the surface for 1 hour to form a stable bis-arylhydrazone bond. The fully functionalized sensor surface is exposed to the complementary, biotinylated DNA strand: 5'GTAAGACACTATTACTGAGGTTTTT-biotin-3' in a hybridization buffer of 50% v/v formamide in PBS (0.01M) pH 7.4. A concentration of 10 nM is chosen for the complementary strand solution. The resulting binding curve of the complementary DNA is depicted in Fig. 1. Note that this graph has already been corrected for a bulk shift that occurred when switching from the pure hybridization buffer to the hybridization buffer with complementary DNA solution. Switching occurs around 205 minutes into the experiment. Hybridization initiates immediately upon complementary DNA solution arrival at the surface. After 30 minutes, pure hybridization buffer is reintroduced to the sensors. A mean net resonance wavelength shift of 74 pm after 30 minutes is observed in 8 microring sensors simultaneously. This wavelength shift is comparable to values reported in literature [6]. This proves both the ability of our sensors to detect complementary DNA sequences and the possibility of a multiplexed detection assay.

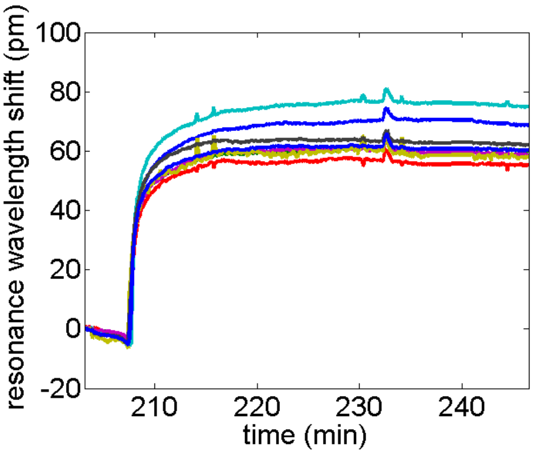

Figure 1. Binding curve for 10nM complementary DNA sequence solution.

3. BINDING CURVE CORRUPTION

Since the resonance splitting in our microring sensors can easily amount to a measurable erroneous, unexpected resonance splitting can severely compromise a recorded binding curve. As resonance splitting is partly a consequence of random process variations on the waveguide edges, it is impossible to predict its strength. This means a resonance selection algorithm cannot differentiate split and unsplit resonances. Jumps between both modes of a split resonance can lead to false positive or even false negative results when the sensor is implemented in a lab-on-a-chip setting.

4. ORIGIN OF RESONANCE SPLITTING

A perfectly symmetric microring resonator mode is twofold degenerate. Both clockwise (CW) and counter-clockwise (CCW) propagation are possible in the microring and both modes are uncoupled. This degeneracy is lifted when the CW-mode and CCW-mode become coupled. Surface roughness on the waveguide edges and the proximity of bus waveguides for microring interrogation form deviations from circular symmetry. These deviations cause forward propagating light to scatter back into the opposite direction, exciting a CCW-mode from a CW-mode and vice versa. Standing-wave modes as a symmetric and antisymmetric superposition of the traveling waves can be considered as the new eigenmodes of the system. They will however no longer be degenerate as a consequence of the symmetry breaking coupling [7]. If the linewidth of the resonance is small enough to distinguish both modes, the resonance splitting will be visible in the output signal. This occurs for high quality resonances. Evidence of this effect is provided in figure 2, which shows both the pass-port and add-port spectrum of a microring in add-drop configuration. Only the input port is excited, so ideally, no power is present in the CCW-mode and the add-port remains dark. The measurement shows that backscattering in the microring waveguide cannot be neglected, resulting in significant power in the add-port and resonance-splitting in the pass-signal amounting up to 50 pm.

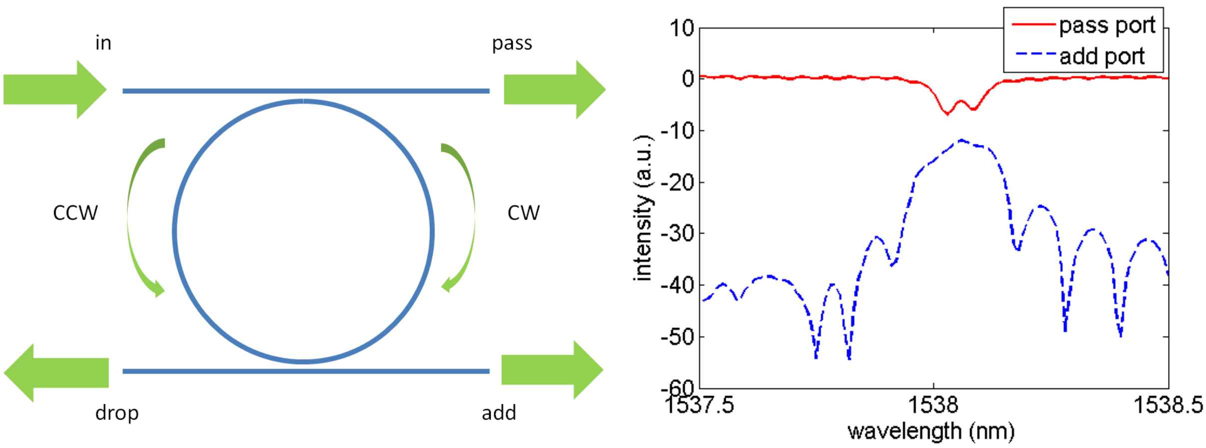

Figure 2. Microring in add-drop configuration (left). Measured spectra showing resonance splitting and backscattered power (right).

5. INTEGRATED INTERFEROMETRIC CIRCUIT

As demonstrated in [8], an interferometric approach can be used to access the normal modes of the microring resonator in an output signal. We have implemented this in an integrated circuit on a single SOI-chip. A layout of the circuit is provided in Fig. 3.

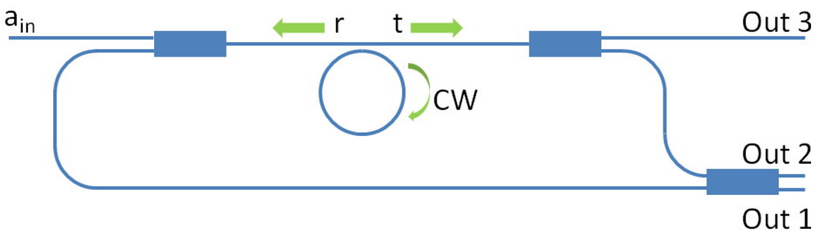

Figure 3. Layout of the integrated interferometric circuit.

Vertical grating couplers are used to couple light from a tunable laser light source into the circuit and collect the power at the output. The input light excites a CW-mode in the microring resonator, a CCW-mode is excited as a consequence of mode-coupling. The normal modes of the microring are a symmetric and antisymmetric superposition of the CW and CCW-mode, so we can express them as follows:

$$a\pm = \frac{1}{\sqrt{2}}\left(a_{CW} \pm a_{CCW}\right) \tag{1}$$

If the coupling per unit time between the bus waveguide and the microring is represented by κ, the fields transmitted and reflected by the resonator are

$$t = \frac{1}{\sqrt{2}} a_{in} + \kappa a_{CW}\, , r = \kappa a_{CCW} \tag{2}$$

Both fields are combined in a multimode interferometer (MMI), which results in the following signals at the different output ports. φ denotes the phase difference between the combining waves.

$$\begin{aligned} out_1 &= \frac{1}{2}\left(\frac{1}{\sqrt{2}} a_{in} + \kappa a_{CW} + \mathrm{e}^{i\phi} a_{CCW}\right) \\ out_2 &= \frac{1}{2}\left(\frac{1}{\sqrt{2}} a_{in} + \kappa a_{CW} - \mathrm{e}^{i\phi} a_{CCW}\right) \\ out_3 &= \frac{1}{\sqrt{2}} t \end{aligned} \tag{3}$$

If we design the circuit such that the phase difference between the reflected and transmitted wave equals a multiple of 0 or π, we see that the signals in output one and two are proportional to the normal modes of the resonator. At the same time, output three is proportional to the pass-signal of the microring resonator in the all-pass configuration. This means we have access to the unsplit, high-Q normal modes of the cavity. If the detection limit of a biosensor is limited by the quality-factor of the resonance, this provides a tool to improve the detection limit significantly. Higher resonator Q-factors give rise to lower detection limits.

6. EXPERIMENTAL RESULTS

The circuit from Fig. 3 is designed and processed in a CMOS pilot line at imec. Using the vertical in- and output couplers on the waveguides, the chip can easily be measured in a fiber-to-fiber configuration. For the junction regions where waveguides are combined and split, MMI 2 × 1 and MMI 2 × 2 couplers are used. The coupling from the microring to the waveguide is ensured by weak evanescent coupling to a neighbouring bus waveguide. To obtain the measured spectra, a SANTEC TSL-510 tunable laser source is used to generate the input signals. Output intensities are measured by a HP-8153 optical power meter. The laser wavelength is swept in 10 pm steps during recording of the power. Figure 4 shows the recorded spectra at the three outputs of the circuit. Output one and two are proportional to the normal modes of the resonator, output three returns the all-pass spectrum. We clearly see the all-pass spectrum shows severe splitting of 60 pm in the resonance. This values is comparable to the 3 dB-bandwidth of the normal mode in output one. The Q-factors of the recorded resonances in output one amount to 2.2×10^4, which is almost a twofold improvement of the resonance quality from output three (1.28×10^4). Notice the distinct asymmetrical shape of the resonance in output two which makes unambiguous definition of a Q-value difficult. Additionally, the extracted normal modes do not correspond exactly with the normal modes we can distinguish in the all-pass signal. This non-ideal behaviour is a consequence of fabrication variations. The 2 × 2 MMI is especially sensitive to this and is not exactly balanced as a result. Also the phase relation between the reflected and the transmitted wave differs slightly from the required value of $k\pi$. This can be solved by careful tuning of the waveguide structures.

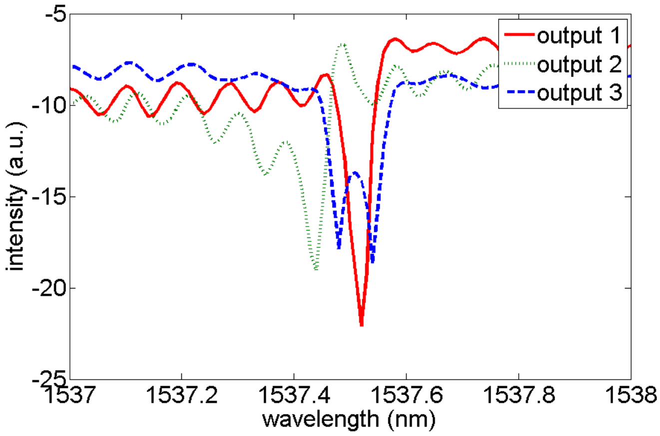

Figure 4. Measured output spectra of the circuit. Output one clearly shows the improvement of the resonance shape compared to the all pass signal in output three.

7. CONCLUSIONS

In this paper, we have demonstrated the successful recognition of a complementary DNA sequence. We have also discussed the problem of microring resonance splitting and shown the possibility of in integrated interferometric setup to resolve this on the SOI-platform. The access to the unsplit normal modes of the resonator allows the improvement of the detection limit of microring resonator biosensors.

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	components (*Invited*) **R. Kaiser**, B. Gomez Saavedra, K.O. Velthaus, M. Gruner, M. Hamacher, D. Hoffmann, M. Schell	S. Kilmurray, R. Bouziane, B.C. Thomsen, S.J. Savory, P. Bayvel	A.R. Dhaini, Shuang Yin, J.A. Hernández, P. Reviriego, T. Shunrong Shen	M. Zalkovskij, R. Malureanu, A. Andryieuski, A. Novitsky, P.U. Jepsen, **A.V. Lavrinenko**, P. T. Tang, C. Kremers, D.N. Chigrin	**Z. Hens**, A. Omari, P. Geiregat, D. Van Thourhout
16:35 We.D1.3 Synchronization of the time-domain wavelength interleaved networks **I. Popescu**, L. Sadeghioon, A. Gravey, P. Gravey, M. Morvan	16:30 We.D2.3 Application of extended Taylor series based finite difference method in photonics (*Invited*) **S. Sujecki**	16:10 We.D3.3 High resolution optical spectral filtering technology: Reaching the sub-GHz resolution range (*Invited*) **D.M. Marom**, D. Sinefeld, O. Golani, N. Goldshtein, R. Zektzer, R. Rudnick	16:20 We.D4.3 Optimal technicians' allocation problem with respect to failure reparation (*Invited*) **C. Mas Machuca**, B. de la Cruz Miranda	16:50 We.D5.3 Low-loss and multi-band metamaterials (*Invited*) **C. Sabah**	17:00 We.D6.3 Light coupling from active polymer layers to hybrid dielectric-plasmonic waveguides (*Invited*) **I. Suárez**, E.P. Fitrakis, H. Gordillo, P. Rodriguez-Cantó, R. Abargues, I. Tomkos, J. Martinez-Pastor
16:50 We.D1.4 Performance enhancement of partial-42.7Gb/s DPSK via an asymmetrical receiver design **N.J. Murray**, O.A. Olubodun, P. Harper, N.J. Doran	16:50 We.D2.4 Modelling the bandwidth behaviour of fibre Bragg gratings excited by low-frequency acoustic waves (*Invited*) **A. de Almeida Prado Pohl**, R.E. da Silva, M.A. Ruggieri Franco, P. de Tarso Neves Jr., H. Bartelt	16:30 We.D3.4 Almost-optimal design for optical networks with Hadoop cloud computing: Ten ordinary desktops solve 500-node, 1000-link, and 4000-request RWA problem within three hours (*Invited*) **Gangxiang Shen**, Yongcheng Li, Limei Peng	16:40 We.D4.4 Balancing the benefits inherent in reconfigurable coherent optical transceivers (*Invited*) **B.T. Teipen**, M.H. Eiselt	17:10 We.D5.4 Energy flow canalization of evanescent cylindrical-vector beams (*Invited*) **C.J. Zapata-Rodríguez**, J.J. Miret	17:20 We.D6.4 Low energy routing platforms for optical interconnects using active plasmonics integrated with silicon photonics (*Invited*) **K. Vyrsokinos**, S. Papaioannou, D. Kalavrouziotis, F. Zacharatos, L. Markey, J-C. Weeber, A. Dereux, A. Kumar, S.I. Bozhevolnyi, M. Waldow, G. Giannoulis, D. Apostolopoulos, T. Tekin, H. Avramopoulos, N. Pleros
17:05 We.D1.5 Performance evaluation of strongly filtered asymmetric 42.7 Gb/s coherent 50% RZ-BPSK system **O.A. Olubodun**, N.J. Murray, P. Harper, N.J. Doran		16:50 We.D3.5 Towards 400G/1T flexible optical transport networks (*Invited*) **E. Pincemin**, M. Song, Y. Loussouarn, G. Thouenon, C. Betoule	17:00 We.D4.5 Energy saving in access networks: Gain or loss from the cost perspective? (*Invited*) P. Wiatr, J. Chen, P. Monti, **L. Wosinska**		
			17:20 We.D4.6 Dynamic traffic provisioning in mixed-line-rate networks with launch power determination (*Invited*) H. Cukurtepe, **A. Yayimli**, M. Tornatore, B. Mukherjee		

Thursday, June 27

SESSION Th.A1 ICTON XII Chair: *Jarmila Müllerová* (8:30 Thursday, June 27)	SESSION Th.A2 ICTON XVI Chair: *Elzbieta Bereś-Pawlik* (8:30 Thursday, June 27)	SESSION Th.A3 NeO III Chair: *Walter Cerroni* (8:30 Thursday, June 27)	SESSION Th.A4 WAOR II Chair: *Pablo Pavón Mariño* (8:30 Thursday, June 27)	SESSION Th.A5 SWP XII Chair: *Sergei Zhukovsky* (8:30 Thursday, June 27)	SESSION Th.A6 NSON Chair: *Marian Marciniak* (8:30 Thursday, June 27)
8:30 Th.A1.1 The time lens concept applied to ultra-high-speed OTDM signal processing (*Invited*) **A.T. Clausen**, E. Palushani, H.C. Hansen Mulvad, H. Hu, J. Laguardia Areal, M. Galili, L.K. Oxenløwe, P. Jeppesen	8:30 Th.A2.1 WDM-enabled optical RAM architectures for ultra-fast, low-power optical cache memories (*Invited*) G.T. Kanellos, T. Alexoudi, D. Fitsios, C. Vagionas, P. Maniotis, S. Papaioannou, A. Miliou, **N. Pleros**	8:30 Th.A3.1 Anycast end-to-end resilience for cloud services over virtual optical networks (*Invited*) Minh Bui, B. Jaumard, **C. Develder**	8:30 Th.A4.1 Performance of ring-resonator based optical backplane in high capacity routers (*Invited*) G. Rizzelli, D. Siracusa, **G. Maier**, M. Magarini, A. Melloni	8:30 Th.A5.1 Radial Bragg laser as a miniaturized rotation sensor (*Invited*) E. Ben-Basat, Y. Karni, **J. Scheuer**	8:30 Th.A6.1 Inverse design of novel nanophotonic structures (*Invited*) **I. Andonegui**, A. Blanco, I. Calvo, A.J. Garcia-Adeva
8:50 Th.A1.2 Effect of all-optical phase regeneration on fiber transmission capacity (*Invited*) G. Hesketh, **P. Horak**	8:50 Th.A2.2 Optimizing silicon-on-oxide 2D-grating couplers **L. Carroll**, D. Gerace, I. Cristiani, L.C. Andreani	8:50 Th.A3.2 Routing and network design for HEAnet (*Invited*) **D. Mehta**, B. O'Sullivan, L. Quesada, M. Ruffini, D. Payne, L. Doyle	8:50 Th.A4.2 Scalable and energy-efficient optical tree-based greedy router (*Invited*) S. Sahhaf, A. Dixit, W. Tavernier, **D. Colle**, M. Pickavet, P. Demeester	8:50 Th.A5.2 Simulation of optical Bloch oscillations and breathing modes in the waveguide arrays **M. Gozman**, Y. Polishchuk, I. Polishchuk	8:50 Th.A6.2 Nonlinear complex photonic structures (*Invited*) **M. Boguslawski**, P. Rose, F. Diebel, S. Brake, C. Denz
9:10 Th.A1.3 Digitally processed modulation formats and integrated photonics for flexible optical metro-access networks (*Invited*) **J.A. Lázaro**, B. Schrenk, M. Malligaraj, I. Cano, M. Sridharan, G. Junyent	9:05 Th.A2.3 Dynamics of SHB and SDP on 9XX EDFAs: Dependence on spectral allocation of input channels **J.M. Ferreira**, D. Fonseca, P. Monteiro, A.N. Pinto, L. Rapp	9:10 Th.A3.3 A column generation approach for large-scale RSA-based network planning (*Invited*) **M. Ruiz**, M. Żotkiewicz, L. Velasco, J. Comellas	9:10 Th.A4.3 An adaptive path restoration algorithm based on power series routing for all-optical networks (*Invited*) C.J.A. Bastos-Filho, R.C. Freitas, **D.A.R. Chaves**, R.C.L. Silva, M.L.P. Freire, H.A. Pereira, J.F. Martins-Filho	9:05 Th.A5.3 Giant circular dichroism in chiral metamaterials **F. Dincer**, M. Karaaslan, E. Unal, M. Bakir, U. Erdiven, C. Sabah	9:10 Th.A6.3 Ways to optimize the second-harmonic response from metamaterials (*Invited*) **R. Czaplicki**, H. Husu, M. Zdanowicz, J. Mäkitalo, K. Koskinen, R. Siikanen, J. Laukkanen, J. Lehtolahti,

Tu.D1.3 Spectral and energy efficiency considerations in mixed-line rate WDM networks with signal quality guarantee (*Invited*) *A. Udalcovs,* ***P. Monti****, V. Bobrovs, R. Schatz, L. Wosinska, G. Ivanovs*	Tu.D2.3 Membrane InP saturable absorbers on silicon as building blocks for transparent optical networks (*Invited*) ***O. Raz****, G. Roelkens, H.J.S. Dorren, M. Tassaert*	Tu.D3.3 Results from the EU project ACCORDANCE on converged OFDMA-PON networks (*Invited*) ***K. Kanonakis****, I. Tomkos, H.-G. Krimmel, F. Schaich, C. Lange, E. Weis, M. Dreschmann, R. Schmogrow, P. Kourtessis, M. Milosavljevic, I. Cano, J. Prat, J.A. Torrijos Gijón*	Tu.D4.3 Storage, schedule and switching – A new data delivery paradigm in the big data era? (*Invited*) ***Weiqiang Sun****, Fengqin Li, Wei Guo, Yaohui Jin, Weisheng Hu*	Tu.D5.3 Inverse scattering problems in subsurface diagnostics of inhomogeneous media (*Invited*) ***K.P. Gaikovich***	Tu.D6.3 Eu-doped polymer fibers (*Invited*) ***R. Caspary****, S. Möhl, A. Cichosch, R. Evert, S. Schütz, H-H. Johannes, W. Kowalsky*
17:00 Tu.D1.4 Energy efficiency analysis of next-generation passive optical network (NG-PON) technologies in a major city network (*Invited*) *S. Lambert, J. Montalvo, J.A. Torrijos,* ***B. Lannoo****, D. Colle, M. Pickavet*	17:00 Tu.D2.4 Highly efficient channel waveguide lasers at 2 µm (*Invited*) *K. van Dalfsen, S. Aravazhi, C. Grivas, S.M. Garcia-Blanco,* ***M. Pollnau***	16:40 Tu.D3.4 Passive optical networks based on OFDM: Perspectives and experimental verifications (*Invited*) ***J. von Hoyningen-Huene****, W. Rosenkranz*	17:00 Tu.D4.4 Adaptive coded-modulation for the next-generation intelligent optical transport networks ***Yequn Zhang****, I.B. Djordjevic*	17:00 Tu.D5.4 Why optical nonlinear characterisation using imaging technique is a better choice? (*Invited*) ***G. Boudebs****, V. Besse, C. Cassagne, H. Leblond, F. Sanchez*	
17:20 Tu.D1.5 Adaptive bit loading in FHT-based OFDM transponders for flexi-grid optical networks ***L. Nadal****, M. Svaluto Moreolo, J.M. Fàbrega, G. Junyent*	17:20 Tu.D2.5 Microring resonators: Opportunities and challenges for future optical networks (*Invited*) ***A. Bianco****, M. Garrich, R. Gaudino, Jinan Xia*	17:00 Tu.D3.5 GPON redundancy eraser algorithm for long-reach extension (*Invited*) ***J. Segarra****, V. Sales, J. Prat*	17:20 Tu.D4.5 Traffic demand estimation for hybrid switching systems ***Pingqing Li****, Weiqiang Sun, Shilin Xiao, Weisheng Hu*	17:20 Tu.D5.5 Plasmonic materials and metamaterials by bottom-up approach: Manufacturing and properties (*Invited*) ***D.A. Pawlak****, M. Gajc, P. Osewski, K. Sadecka, A. Stefanski, A. Klos, A. Belardini, G. Leahu, C. Sibilia*	

20:00 ***Gala Dinner at Restaurant "La Cartuja"***

Wednesday, June 26

SESSION We.A1 ICTON VIII Chair: *João Pedro* (9:00 Wednesday, June 26)	**SESSION We.A2** PICAW II Chair: *Peter Horak* (9:00 Wednesday, June 26)	**SESSION We.A3** Access III Chair: *Ioannis Tomkos* (9:00 Wednesday, June 26)	**SESSION We.A4** GOC I Chair: *Lena Wosinska* (9:00 Wednesday, June 26)	**SESSION We.A5** SWP VIII Chair: *Brana Jelenković* (9:00 Wednesday, June 26)	**SESSION We.A6** ESPC I Chair: *Crina Cojocaru* (9:00 Wednesday, June 26)
9:00 We.A1.1 Creating new generation optical network service (*Invited*) ***N. Yamanaka****, H. Takeshita, S. Okamoto, T. Sato*	9:00 We.A2.1 Optical delay in silicon photonic crystals using ultrafast indirect photonic transitions (*Invited*) ***D.M. Beggs****, I.H. Rey, T. Kampfrath, N. Rotenberg, L. Kuipers, T.F. Krauss*	9:00 We.A3.1 Optical single sideband generation optimized to support multi-services OFDM over hybrid long-reach FTTH networks ***P. Almeida****, H. Silva*	9:00 We.A4.1 Energy-efficient space-time optical interconnection architectures for data centers (*Invited*) ***P. Castoldi****, I. Cerutti, P.G. Raponi, N. Andriolli, O. Liboiron-Ladouceur*	9:00 We.A5.1 Self-pulsing and nonlinear dynamics in micro and nanolasers (*Invited*) ***S. Barbay****, F. Selmi, S. Haddadi, R. Braive, I. Sagnes, R. Kuszelewicz, A.M. Yacomotti*	9:00 We.A6.1 Asymmetric light propagation in photonic devices (*Invited*) ***H. Kurt***
9:20 We.A1.2 Dynamic grooming and spectrum allocation in optical metro ring networks with flexible grid (*Invited*) *F. Musumeci, F. Puleio,* ***M. Tornatore***	9:20 We.A2.2 Numerical simulation and design of organic integrated optical circuits: The PHOTOPOLIS approach (*Invited*) ***T. Kamalakis****, D. Alexandropoulos, G. Dede, P. Kanakis, T. Politi, N. Vainos*	9:20 We.A3.2 OFDM-PON performance with limited quantization ***X. Escayola****, I. Cano, M. Santos, J. Prat*	9:20 We.A4.2 Enhancing data centre networking using energy aware optical interconnects (*Invited*) ***I. Glesk****, T. Osadola, S. Idris*	9:20 We.A5.2 Effect of shell size on single photon emission performances of core/shell dot-in-rods colloidal nanocrystals (*Invited*) *F. Pisanello, G. Leménager, L. Martiradonna, L. Carbone, A. Bramati,* ***M. De Vittorio***	9:20 We.A6.2 Controlling the emission from single quantum dots with electro-opto-mechanical photonic crystal cavities (*Invited*) ***L. Midolo****, F. Pagliano, T. B. Hoang, T. Xia, F.W.M. van Otten, A. Fiore, L.H. Li, E.H. Linfield, M. Lermer, S. Höfling*
9:40 We.A1.3 Flexible next-generation optical access (*Invited*) ***M. Forzati****, A. Gavler*	9:40 We.A2.3 A polymer waveguide-based 40 Gb/s optical bus backplane for board-level optical interconnects (*Invited*) ***N. Bamiedakis****, A. Hashim, R.V. Penty, I.H. White*	9:35 We.A3.3 16×2.5 Gbit/s and 5 Gbit/s WDM PON based on self-seeded RSOA ***Sy Dat Le****, Q. Deniel, F. Saliou, A. Lebreton, P. Chanclou*	9:40 We.A4.3 Energy-efficient, high-performance optoelectronic packet switching for intra-data center network (*Invited*) ***Ken-ichi Kitayama****, S. Debnath, Y. Yoshida, R. Takahashi, A. Hiramatsu*	9:40 We.A5.3 Super spontaneous four-wave mixing (*Invited*) ***M. Liscidini****, T. Onodera, L.G. Helt, J.E. Sipe*	9:40 We.A6.3 Active photonic crystal switches: Modeling, design and experimental characterization (*Invited*) ***M. Heuck****, Y. Yu, P.T. Kristensen, N. Kuznetsova, K. Yvind, J. Mørk*
10:00 We.A1.4 Dispersion constraints in optical burst switched metropolitan networks with WDM/OCDM technology ***L.H. Bonani****, A.B. dos Santos, L. Galdino*	10:00 We.A2.4 Robust multi-objective optimization of 2x2 multimode interference coupler using expected improvement ***S. ur Rehman****, M. Langelaar, F. van Keulen*	9:50 We.A3.4 Optimal trade-off for a bidirectional single-fibre single-wavelength TDM-PON rSOA-based ONU ***E.T. López****, V. Polo, J.A. Lázaro, J. Prat*	10:00 We.A4.4 Energy saving in TWDM(A) PONs: Challenges and opportunities (*Invited*) ***L. Valcarenghi****, P. Castoldi, Y. Yoshida, A. Maruta, Ken-ichi Kitayama*	10:00 We.A5.4 Surface enhanced Raman scattering and photo-luminescence through Bloch surface waves in dielectric multilayers (*Invited*) *S. Pirotta, X.G. Xu, A. Delfan, S. Mysore, S. Maiti, G. Dacarro, M. Patrini, G. Guizzetti, D. Bajoni, J.E. Sipe, G.C. Walker, M. Liscidini,* ***M. Galli***	10:00 We.A6.4 Multiple functionality in III-V on SOI hybrid photonic crystals for systems applications (*Invited*) *F. Raineri, P. Monnier,* ***R. Raj****, A. Bazin*
10:15 We.A1.5 An efficient add/drop architecture for large-scale subsystem-modular OXC ***H. Ishida,***		10:05 We.A3.5 Off-set filtering for enhanced transmission in RSOA based WDM-PON ***A. Gatto****, P. Parolari, L. Marazzi, M. Brunero,*	10:20 We.A4.5 A blocking analysis for green WDM networks with transponder power management ***F. Musumeci****, M. Tornatore,*		

Tremblay (13:50 Tuesday, June 25)	Pohl (13:50 Tuesday, June 25)	(13:30 Tuesday, June 25)	Parca (13:50 Tuesday, June 25)	Chair: **Rafał Kotyński** (13:50 Tuesday, June 25)	Vigreux (13:30 Tuesday, June 25)
13:50 Tu.C1.1 Trunk reservation for elastic optical networks (*Invited*) F. Lezama Cruzvillasante, **F. Callegati**, W. Cerroni, L.H. Bonani	13:50 Tu.C2.1 Are few-mode fibres: A practical solution to the capacity crunch? (*Invited*) **A. Ellis**, N. Doran	13:30 Tu.C3.1 UltraFlow Access Networks: A dual-mode solution for the access bottleneck (*Invited*) **L.G. Kazovsky**, A.R. Dhaini, M. De Leenheer, T.S. Shen, Shuang Yin, B.A. Detwiler	13:50 Tu.C4.1 On the cost efficiency of flexible optical networking compared to conventional SLR/MLR WDM networks (*Invited*) I. Stiakogiannakis, E. Palkopoulou, **I. Tomkos**	13:50 Tu.C5.1 3D optical data storage by nonlinear processes in thin films of coumarin-containing copolymers (*Invited*) **D. Gindre**, E. Champigny, K. Iliopoulos, M. Sallé	13:30 Tu.C6.1 Chalcogenide-silica fibers: A new base for linear and nonlinear nanophotonic devices (*Invited*) **M.A. Schmidt**
14:10 Tu.C1.2 An elastic networks OMNET++ -based simulator (*Invited*) A. Asensio, A. Castro, L. Velasco, **J. Comellas**	14:10 Tu.C2.2 Ultra-large capacity transmission over trans-oceanic distances with multi-core fibers and EDFAs (*Invited*) **M. Suzuki**, H. Takahashi, K. Igarashi, K. Takeshima, T. Tsuritani, I. Morita	13:50 Tu.C3.2 Towards ultra-dense wavelength-to-the-user: The approach of the COCONUT project (*Invited*) J. Prat, M. Angelou, C. Kazmierski, R. Pous, M. Presi, A. Rafel, G. Vall-llosera, I. Tomkos, **E. Ciaramella**	14:10 Tu.C4.2 Twenty years of open fibre network in Stockholm: A socio-economic study (*Invited*) **M. Forzati**, C. Mattsson	14:10 Tu.C5.2 Self-assembly of nanostructures by a phase separation in holographic layers of dichromated polysaccharide (*Invited*) S. Savić-Šević, D. Pantelić, B. Jokić, **B. Jelenković**	13:50 Tu.C6.2 Chalcogenide glass fibers for photonic devices (*Invited*) **J.L. Adam**, L. Brilland, P. Toupin, V. Nazabal, J. Troles
14:30 Tu.C1.3 Optimization algorithms for data center location problem in elastic optical networks (*Invited*) **M. Klinkowski**, K. Walkowiak, R. Goścień	14:30 Tu.C2.3 On the dependence of differential mode delay of few-mode fibers with the number of modes (*Invited*) F. Ferreira, **D. Fonseca**, H. Silva	14:10 Tu.C3.3 High-speed coherent WDM PON for next-generation access network (*Invited*) **Y.C. Chung**	14:30 Tu.C4.3 Total cost of ownership comparison between single and mixed line rates networks (*Invited*) **A.N. Pinto**, R.M. Morais, J. Pedro, P. Monteiro	14:30 Tu.C5.3 Fluorescent nanoparticles for biosensing applications (*Invited*) **S. Tomljenovic-Hanic**, B.C. Gibson, T.J. Karle, A. Khalid, K. Chung, D.A. Simpson, P. Tran, P. Domachuk, H. Tao, J.E. Moreau, D.L. Kaplan, F.G. Omenetto, H. Amekura, A.B. Djurisic	14:10 Tu.C6.3 Third-order non-linear optical response in chalcogenide glasses: Measurement and evaluation (*Invited*) **E. Romanova**, K. Chumakov, A. Mouskeftaras, S. Guizard, N. Abdel-Moneim, D. Furniss, A.B. Seddon, T.M. Benson
14:50 Tu.C1.4 Spectrum-sliced elastic optical networking (*Invited*) **H. Waldman**, R.C. Almeida Jr., K.D. Assis, R.C. Bortoletto	14:50 Tu.C2.4 Generating versatile waveforms using single dual-drive modulator (*Invited*) B. Dai, S. Shimizu, **Xu Wang**, N. Wada	14:30 Tu.C3.4 Ultra high capacity PON systems (*Invited*) **A. Teixeira**, G. Parca, A. Shahpari, J. Reis, R. Ferreira, A. Abdalla, M. Lima, V. Carrozzo, G. Tosi-Beleffi	14:50 Tu.C4.4 The cost dependence between the grooming scheme, the node architecture and the traffic pattern in optical networks (*Invited*) **R.M. Morais**, J. Pedro, P. Monteiro, A.N. Pinto	14:50 Tu.C5.4 Investigations at nanoscale by using fluorescence in apertureless scanning near field microscopy (*Invited*) **G.A. Stanciu**, D.E. Tranca, R. Hristu, C. Stoichita, S.G. Stanciu	14:30 Tu.C6.4 Nd^{3+} doped phosphate glass optical fibre lasers (*Invited*) **N.G. Boetti**, J. Lousteau, E. Mura, G.C. Scarpignato, D. Milanese
15:10 Tu.C1.5 Flexible-sense optical transmission (*Invited*) V. Rozental, G. Bruno, A. Soso, M. Camera, **D.A.A. Mello**	15:10 Tu.C2.5 Robustness to mechanical perturbations of centre-launching technique in multi-mode fibres for transparent optical interconnects **A. Boletti**, P. Boffi, A. Gatto, P. Martelli, E. Centeno Nieves, M. Martinelli	14:50 Tu.C3.5 COCONUT requirements for residential, business and outdoor scenarios **G. Vall-llosera**, A. Rafel, E. Ciaramella, J. Prat	15:10 Tu.C4.5 Performance comparison of optical channel formats to realize 400G data rates in transport networks under dynamic traffic (*Invited*) **J. Pedro**, A. Eira, J. Pires	15:10 Tu.C5.5 Detecting cancerous tissues in human body by means of fiber fluorescent spectroscopy (*Invited*) **E. Bereś-Pawlik**, H. Sławska, Ł. Klonowski	14:50 Tu.C6.5 Design of rare-earth doped microspheres lasers (*Invited*) P. Bia, L. Mescia, O. Losito, M. De Sario, D. Ristic, M. Ferrari, G.C. Righini, **F. Prudenzano**
Coffee break (15:30 – 16:00)	**Coffee break** (15:30 – 16:00)	**Coffee break** (15:05 – 15:40)	**Coffee break** (15:30 – 16:00)	**Coffee break** (15:30 – 16:00)	**Coffee break** (15:10 – 15:40)
SESSION Tu.D1 **ICTON VII** Chair: **Burak Kantarci** (16:00 Tuesday, June 25)	**SESSION Tu.D2** **PICAW I** Chair: **Lech Wosinski** (16:00 Tuesday, June 25)	**SESSION Tu.D3** **Access II** Chair: **Leonid Kazovsky** (15:40 Tuesday, June 25)	**SESSION Tu.D4** **ISOND** Chair: **Milorad Cvijetic** (16:00 Tuesday, June 25)	**SESSION Tu.D5** **SWP VII** Chair: **Pavel Cheben** (16:00 Tuesday, June 25)	**SESSION Tu.D6** **Glasses II** Chair: **Sławomir Sujecki** (15:40 Tuesday, June 25)
16:00 Tu.D1.1 Dynamic deployment of virtual GMPLS-controlled elastic optical networks using a virtual network resource broker on the ADRENALINE testbed (*Invited*) **R. Vilalta**, R. Muñoz, R. Casellas, R. Martínez	16:00 Tu.D2.1 Photonic components for signal routing in optical networks on chip (*Invited*) G. Calò, **V. Petruzzelli**	15:40 Tu.D3.1 A study of flexible bandwidth allocation in statistical OFDM-based PON (*Invited*) **I.N. Cano**, X. Escayola, A. Peralta, V. Polo, M.C. Santos, J. Prat	16:00 Tu.D4.1 An evolutionary spectrum assignment algorithm for elastic optical networks (*Invited*) **R.C. Almeida Jr.**, R.A. Delgado, C.J.A. Bastos-Filho, D.A.R. Chaves, H.A. Pereira, J.F. Martins-Filho	16:00 Tu.D5.1 High resolution Fourier-transform microspectroscopy based on spiral silicon waveguides (*Invited*) A.V. Velasco, **M.L. Calvo**, P. Cheben, M. Florjańczyk, P.J. Bock, A. Delâge, J.H. Schmid, J. Lapointe, S. Janz, Dan-Xia Xu, M. Vachon	15:40 Tu.D6.1 Te-Ge-Se thermally co-evaporated films: Elaboration, characterization and use for the manufacture of IR rib waveguides, basic elements of CO_2 microsensors (*Invited*) **C. Vigreux**, M. Vu Thi, G. Maulion, R. Kribich, A. Pradel
16:20 Tu.D1.2 Dynamic management of bursty traffic over multiple channels (*Invited*) **A.K. Somani**	16:20 Tu.D2.2 Silicon CMOS photonics platform for enabling high-speed DQPSK transceivers (*Invited*) **P. Sanchis**, M. Aamer, A. Brimont, A.M. Gutierrez, N. Sotiropoulos, H. de Waardt, D.J. Thomson, F.Y. Gardes, G.T. Reed, K. Ribaud, P. Grosse, J.M. Hartmann, J-M. Fedeli, D. Marris-Morini, E. Cassan, L. Vivien, D. Vermeulen, G. Roelkens, A. Hakansson	16:00 Tu.D3.2 Dynamic bandwidth allocation with optimal wavelength switching in TWDM-PONs (*Invited*) **A. Dixit**, B. Lannoo, D. Colle, M. Pickavet, P. Demeester	16:20 Tu.D4.2 Flow controlled scalable optical packet switch for low latency flat data center network (*Invited*) **N. Calabretta**, S. Di Lucente, Jun Luo, A. Rohit, K. Williams, H. Dorren	16:20 Tu.D5.2 Optical Haar transform for 2D processing and compression (*Invited*) **G. Parca**, P. Teixeira, C. Vicente, A. Teixeira	16:00 Tu.D6.2 Active waveguides for Mid-IR (3–4 µm) wavelengths fabricated by femtosecond laser inscription in Dy^{3+} doped tellurite glass (*Invited*) **T.T. Fernandez**, B.D.O. Richards, G. Jose, A. Jha, J. Hoyo, A. Ruiz De la Cruz, J. Solis
16:40	16:40	16:20	16:40	16:40	16:20